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TRACTION MOTOR AND DRIVE SYSTEM

Technical field:

The present invention relates to a traction motor and a drive system, e.g. for railway locomotives and motor coaches, in which the traction motor and/or other electric machines included in the system are provided with a magnetic circuit comprising a magnetic core and at least one winding.

Background art:

The magnetic circuit in electric machines usually comprises a laminated core, e.g. of sheet steel surrounded and fixed with a welded construction. To provide ventilation and cooling the core is often divided into stacks with radial and/or axial ventilation ducts. For larger machines the laminations are punched out in segments which are attached to the frame of the machine, the laminated core being held together by pressure fingers and pressure rings. The winding of the magnetic circuit is disposed in slots in the core, the slots generally having a cross section in the shape of a rectangle or trapezium.

In multi-phase electric machines the windings are made as either single or double layer windings. With single layer windings there is only one coil side per slot, whereas with double layer windings there are two coil sides per slot. By coil side is meant one or more conductors combined vertically or horizontally and provided with a common coil insulation, i.e. an insulation designed to withstand the rated voltage of the machine to earth.

Double-layer windings are generally made as diamond windings whereas single layer windings in the present context can be made as diamond or flat windings. Only one (possibly two) coil width exists in diamond windings whereas flat windings are made as concentric windings, i.e. with widely varying coil width. By coil width is meant the

distance in arc dimension between two coil sides pertaining to the same coil.

Normally all large machines are made with double-layer winding and coils of the same size. Each coil is placed with one side in one layer and the other side in the other layer. This means that all coils cross each other in the coil end. If there are more than two layers these crossings complicate the winding work and the coil end is less satisfactory.

Before it became possible to use industrial frequency (50 or 60 Hz) for traction motors, the first alternating voltage systems were electrified with low-frequency voltage (15 to $16^2/3$ or 25 Hz). The traction motor used for a long time in such systems was a single-phase series commutator motor, also known as a single-phase traction motor. This functions almost like a direct current motor except that both field and rotor current are reversed every half period since it is supplied with alternating current. For commutation to take place without damaging arcing at the commutator, low frequency and motors with low speed had to be chosen.

The main advantage with alternating systems as opposed to direct current systems is that the alternating voltage can be transformed (even though direct voltage can nowadays be transformed with so-called choppers). It is thus possible to maintain a relatively high voltage on the overhead conductor in relation to the voltage with which the motor operates. Due to the high voltage in the overhead conductor the current becomes lower, thus giving better power transmission ability and lower losses in the line network. Supply stations can be located rather far apart (30-120 km).

The most commonly used traction motor today is the three phase asynchronous motor due to its simplicity and robustness. It is fed by three phase current with variable

voltage and frequency which is produced by power semiconductor circuitry from the line voltage (dc system) or from the transformer secondary voltage (ac system).

Machines of the above-mentioned type, with conventional stator winding, cannot be connected to a high-voltage network at e.g. 15 kV without the use of a transformer to lower the voltage. The use of a motor in this way, connected to the high-voltage network via a transformer, entails a number of drawbacks as compared with if the motor could be connected directly to the high-voltage network. The following drawbacks may be noted, among others:

- the transformer is expensive, increases transport costs and requires space
- the transformer lowers the efficiency of the system
- the transformer consumes reactive power
- a conventional transformer contains oil, with the associated risks.

Description of the invention:

The object of the present invention is to provide a motor and a drive system therefor for electric railway operation and the like, which solves some of the problems inherent in known systems in this area.

The present invention provides a motor according to claim 1 and a drive system according to claim 6 or claim 7.

The invention is thus based on a special technique for constructing electric machines, motors, generators, transformers, etc. in which the electric windings are produced with insulation other than oil, and preferably dry, in a special manner. This permits either elimination of the

transformer and/or the construction of transformers without the drawbacks inherent in conventional ones that have been mentioned above.

The invention may naturally also include such special machines combined with conventional machines.

Thus a machine of the type to which the invention relates may be a transformer or a traction motor which does not then need any transformer. The alternatives may of course be combined.

The drive system and the components according to the invention can be adapted to the electric supply system of various railway systems and, with applicable modifications, is intended for railway systems with external power supply or with their own power supply system, for railways with different voltage levels and different frequencies and for both alternating and direct current systems, as well as for both synchronous and asynchronous motor operation.

In cases when a transformer is deemed necessary, it is an object of the present invention that the transformer shall be manufactured using a cable of the same type and in corresponding manner as for the other electric machines included in the drive system.

The advantage gained by satisfying the above objects is the avoidance of an intermediate, oil-filled transformer, the reactance of which otherwise consumes reactive power.

To achieve this, the magnetic circuit and its conductors in at least one of the electric machines included in the vehicle are produced with threaded permanently insulated cable the exterior of which is connected to a selected potential such as earth.

The major and essential difference between known technology and the embodiment according to the invention is thus that the latter includes in at least one machine which, due to the nature of its magnetic circuit can be directly connected via breakers and isolators to a high supply voltage, up to between 10 and 800 kV. The magnetic circuit thus comprises one or more laminated cores with a winding consisting of a threaded cable having one or more permanently insulated conductors having a semiconducting layer both at the conductor and outside the insulation, the outer semiconducting layer being connected to earth potential.

To solve the problems arising with direct connection of electric machines, both rotating and static machines, to all types of high-voltage power networks, at least one machine in the drive system according to the invention has a number of features as mentioned above, which differ distinctly from known technology. Additional features and further embodiments are defined in the dependent claims and are discussed in the following.

The features mentioned above and other characteristics of the drive system and at least one of the electric machines included therein according to the invention, include the following:

- The winding for the magnetic circuit is produced from a cable having one or more permanently insulated

conductors with two semiconducting layers, one surrounding the strands and one forming a sheath. Some typical conductors of this type have insulation of cross-linked polyethylene or ethylene propylene rubber. For the present purpose the conductors may be further developed both as regards the strands in the conductor and the nature of the outer sheath.

- Cables with circular cross section are preferred, but cables with some other cross section may be used in order to obtain better packing density, for instance.

- Such a cable allows the laminated core to be designed according to the invention in a new and optimal way as regards slots and teeth.

- The winding is preferably manufactured with insulation in steps for best utilization of the laminated core.

- The winding is preferably manufactured as a multi-layered, concentric cable winding, thus enabling the number of coil-end intersections to be reduced.

- The slot design may be suited to the cross section of the winding cable so that the slots are in the form of a number of cylindrical openings running axially and/or radially outside each other and having an open waist running between the layers of the armature winding.

- The design of the slots may be adjusted to the relevant cable cross section and to the stepped insulation of the winding. The stepped insulation allows the magnetic core to have substantially constant tooth width, irrespective of the radial extension.

- The above-mentioned further development as regards the outer sheath entails that at suitable points along the length of the conductor, the outer sheath is cut off, each cut partial length being connected directly to earth potential.

The use of a cable of the type described above allows the entire length of the outer semiconducting sheath of the winding, as well as other parts of the drive system, to be kept at earth potential. An important advantage is that the electric field is close to zero within the coil-end region outside the outer semiconducting layer. With earth potential on the outer layer the electric field need not be controlled. This means that no field concentrations will occur either in the core, in the coil-end regions or in the transition between them.

The mixture of insulated and/or uninsulated impacted strands, or transposed strands, results in low stray losses.

The cable for high voltage used in the magnetic circuit winding is built up of an inner core/conductor with a plurality of strands, at least one semiconducting layer, the innermost being surrounded by an insulating layer, which is in turn surrounded by an outer semiconducting layer having an outer diameter in the order of 6-250 mm and a conductor area in the order of 10-3000 mm^2.

If at least one of the machines in the plant according to the invention is constructed in the manner specified, start and control of the motor(s) used in the locomotive of motor coach can be achieved with the start methods, known per se.

According to a particularly preferred embodiment of the invention, at least two of these layers, preferably all three, have the same coefficient of thermal expansion. The decisive benefit is thus gained that defects, cracks and the like are avoided during thermal movement in the winding.

Since the insulation system, suitably permanent, is designed so that from the thermal and electrical point of view it is dimensioned for over 10 kV, the system can be connected to high-voltage power networks without any intermediate step-down transformer, thereby achieving the advantages referred to above.

The above-mentioned and other advantageous embodiments of the invention are defined in the dependent claims.

Brief description of the drawings:

The invention will be described in more detail in the following description of a preferred embodiment of the construction of the magnetic circuit of an electric machine, with reference to the accompanying drawings in which

Figure 1 shows a schematic end view of a sector of the stator in an electric machine in the plant according to the invention;

Figure 2 shows an end view, step-stripped, of a cable used in the winding of the stator according to Figure 1; and

Figures 3 to 5 show traction motor drive systems according to different embodiments of the invention.

Description of preferred embodiments:

In the schematic end view of a sector of the stator 1 according to Figure 1, pertaining to an electric machine of

rotating type included in the plant according to the invention, the rotor 2 of the machine is also indicated. The stator 1 is composed of a laminated core. Figure 1 shows a sector of the machine corresponding to one pole pitch. A number of teeth 4 extend radially in from a yoke part 3 of the core towards the rotor 2 and are separated by slots 5 in which the stator winding is arranged. Cables 6 forming this stator winding are high-voltage cables which may be of substantially the same type as those used for power distribution, e.g. PEX cables. One difference is that the outer, mechanically-protective sheath, and the metal screen normally surrounding such power distribution cables are eliminated so that the cable for the present application comprises only the conductor and at least one semiconducting layer on each side of an insulating layer. Thus, the semiconducting layer lies naked on the surface of the cable.

The cables 6 are illustrated schematically in Figure 1, only the conducting central part of each cable part or coil side being drawn in. As can be seen, each slot 5 has varying cross section with alternating wide parts 7 and narrow waist parts 8. The wide parts 7 are substantially circular and surround the cabling. The waist parts 8 serve to radially fix the position of each cable. The cross section of the slot 5 also narrows radially inwards. This is because the voltage on the cable parts is lower the closer to the radially inner part of the stator 1 they are situated. Slimmer cabling can therefore be used towards the inside, whereas coarser cabling is necessary further out. In the example illustrated cables of three different dimensions are used, arranged in three correspondingly dimensioned sections 51, 52, 53 of slots 5.

The above description of the magnetic circuit for a rotating electric machine built up with the cable 6 is also applicable to static electric machines such as transformers,

reactor windings and the like. The following important advantages are obtained both from the design and the manufacturing point of view:

- the windings of the transformer can be constructed without consideration to any electric field distribution and the problematical transposition of parts in known technology is thus unnecessary,

- the transformer core can be designed without taking into consideration any electric field distribution,

- no oil is required for electric insulation of cable and winding and instead the cable and winding can be surrounded by air or by a non-flammable or slowly burning liquid,

- in many applications no special bushing is required as is the case for oil-filled transformers, for electrical communication between the outer connections of the transformer and the coils/windings located therein,

- the lack of oil greatly reduces the risk of fire and explosion in a transformer of the invention,

- the transformer can be made rigid than a conventional transformer, increasing its ability to withstand short circuits,

- the transformer is less noisy, cleaner and requires less maintenance, and

- the manufacturing and testing technology required for a dry transformer with magnetic circuit as described above, is considerably simpler than that required for conventional transformers/reactors.

Figure 2 shows a step-wise stripped end view of a high-voltage cable for use in an electric machine included in the plant according to the present invention. The high-voltage cable 6 comprises one or more conductors 31, each of which

comprises a number of strands 36 which together give a circular cross section of copper (Cu), for instance. These conductors 31 are arranged in the middle of the high-voltage cable 6 and are surrounded in the embodiment shown by a part insulation 35. However, it is feasible for the part insulation 35 to be omitted on one of the conductors 31. In the present embodiment of the invention the conductors 31 are together surrounded by a first semiconducting layer 32. Around this first semiconducting layer 32 is an insulating layer 33, e.g. PEX insulation, which is in turn surrounded by a second semiconducting layer 34. Thus the high-voltage cable need not include any metallic screen or outer sheath of the type that normally surrounds such a cable for power distribution. As traction equipment often becomes very warm, the insulating layer 33 can comprise heat resistant polymers, e.g. silicone rubber or fluorinated polymers. The semiconducting layers 32, 34 may comprise similar material to the insulating layer but with conducting particles, such as carbon black, soot or metallic particles, embedded therein. Generally it has been found that a particular insulating material has similar mechanical properties when containing no, or some, carbon particles.

The use of electric machines provided with magnetic circuits of the type described above enables the electric supply of traction motors, as well as the traction motors themselves, to be greatly simplified and made more efficient. In railway operation with alternating voltage the supply voltages currently used are generally 15 kV, $16^2/3$ Hz, 11 kV 25 Hz or 25 kv, 50/60 Hz in the supply line 104 from which the current collector 112 of the locomotive supplies one or more traction motors 114, as shown in Figures 3 to 5.

Known traction motors for alternating voltage are normally driven by voltages of up to 1 kV and the locomotive

must therefore be equipped with a transformer and with speed-control equipment, the latter constituting thyristors in modern locomotives.

The transformers used in the known locomotive are oil-filled and have a number of mechanical and electrical drawbacks, as well as incurring environmental problems. The rotating machines and used for converting and operation in the known locomotive have various problems, both mechanical and electrical, that can be dealt with to a more or less satisfactory extent.

The above-mentioned problems can be eliminated or minimized by designing the magnetic circuits in at least one of the electric machines of the system in accordance with the present invention.

Figures 3 to 5 show a 3-phase asynchronous motor 114 providing the mechanical power for the locomotive and having a winding formed from a high-voltage cable as exemplified in Figure 2. The winding of the motor 114 has the advantages which have been described above.

Figure 3 shows a drive system for the motor, comprising a transformer 122 and a thyristor bridge 123, connected via a smoothing and filtering circuit 124 to a dc/3-phase ac converter 125 which supplies the 3-phase motor 114. The transformer 122 has a winding formed from a cable such as is shown in Figure 2. This transformer therefore has the advantages listed above and is also lighter and less bulky than a known oil-filled transformer.

Figure 4a shows a drive system including a rotating converter 130 comprising a motor M supplied directly from the current collector 112 and a generator G which supplies the 3-phase motor 114 via a regulator device 131. Tap connections 132a, 132b can be used to control the voltage supplied to the motor 114 and the number of poles connected for coarse speed control.

Figure 4b shoes an alternative system in which the rotating converter 130, which preferably generates multiphase, e.g. six-phase ac, is connected to a rectifier bridge 133 which supplies the motor 114 via a dc/3-phase ac converter 125. Figure 4c shows a further alternative system in which the supply from the rotating converter 130 to the motor 114 is via an ac/ac frequency converter 134.

In the systems shown in Figures 4a, 4b and 4c, either or both of the motor M and generator G are wound using a cable as exemplified in Figure 2. The motor and generator may be separate machines sharing a common shaft, or alternatively the rotating converter may comprise a single unit as described, for example, in German Patents 372390, 386561 and 406371. The rotating converter may also be a phase converter as described in "Das Handbuch der Lokomotiven", pp. 254-255, "Electrischer Bahnen" eb, 85. Jahrgang, Heft 12/1987, pp. 388-389, or Lueger, "Lexicon der Technik", p.395.

Figure 5 shows a system in which the motor 114 is a high voltage motor which is supplied by a regulator device 135 connected to the current collector 112. The regulator device is preferably a direct semiconductor ac/ac converter. Since the motor 114 is supplied with a high voltage, no transformer or other voltage changing means is required and

the drive system has the advantage of being compact and light.

Although certain voltage values have been noted above, these shall only be considered as examples. Similarly, various combinations of conventionally designed electric machines and electric machines provided with the magnetic circuit according to the invention are feasible. The invention shall not therefore be deemed as restricted to the systems described with reference to the drawings, but covers all feasible systems defined in the appended claims.

Although it is preferred that the electrical insulation should be extruded in position, it is possible to build up an electrical insulation system from tightly wound, overlapping layers of film or sheet-like material. Both the semiconducting layers and the electrically insulating layer can be formed in this manner. An insulation system can be made of an all-synthetic film with inner and outer semiconducting layers or portions made of polymeric thin film of, for example, PP, PET, LDPE or HDPE with embedded conducting particles, such as carbon black or metallic particles and with an insulating layer or portion between the semiconducting layers or portions.

For the lapped concept a sufficiently thin film will have butt gaps smaller than the so-called Paschen minima, thus rendering liquid impregnation unnecessary. A dry, wound multilayer thin film insulation has also good thermal properties.

Another example of an electrical insulation system is similar to a conventional cellulose based cable, where a thin cellulose based or synthetic paper or non-woven

material is lap wound around a conductor. In this case the semiconducting layers, on either side of an insulating layer, can be made of cellulose paper or non-woven material made from fibres of insulating material and with conducting particles embedded. The insulating layer can be made from the same base material or another material can be used.

Another example of an insulation system is obtained by combining film and fibrous insulating material, either as a laminate or as co-lapped. An example of this insulation system is the commercially available so-called paper polypropylene laminate, PPLP, but several other combinations of film and fibrous parts are possible. In these systems various impregnations such as mineral oil can be used.